



NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**OPTIMAL LOCATION OF MARINE FORCES RESERVE
UNITS BY DEMOGRAPHICS**

by

Paul M. Brisker

June 2014

Thesis Co-Advisors:

Javier Salmeron

Robert Dell

Second Reader:

Chad Seagren

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 2014	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE OPTIMAL LOCATION OF MARINE FORCES RESERVE UNITS BY DEMOGRAPHICS			5. FUNDING NUMBERS	
6. AUTHOR(S) Paul M. Brisker				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB protocol number ____N/A____.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE A	
13. ABSTRACT (maximum 200 words) This research creates Marine Corps Reserve Optimizer (MCRO), an optimization tool to aid Marine Forces Reserve (MARFORRES) in the task of geographically situating their subordinate units with respect to demographics. It implements an integer linear program that selects optimal locations for all candidate moving units based on the projected availability of qualified recruits in candidate areas. MCRO optimizes to (a) minimize a penalty function that measures stress with respect to demographics, and (b) minimize unit movement. Two base cases are demonstrated, one illustrating the total demographic stress with 2011 population data without allowing unit movements, and another with the projected 2036 population under the same conditions. We then allow MCRO to recommend movements, and find that (i) the relocation of 10 units reduces the number of areas experiencing the highest penalty from nine to three, and (ii) all stress can be relieved in 56 movements. Finally, we use MCRO to evaluate and quantify the demographic impact of four possible unit movements MARFORRES is currently considering.				
14. SUBJECT TERMS Optimization, discrete mathematics, demographics, Marine Forces Reserve, manpower			15. NUMBER OF PAGES 77	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU	

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

**OPTIMAL LOCATION OF MARINE FORCES RESERVE UNITS BY
DEMOGRAPHICS**

Paul M. Brisker
Captain, United States Marine Corps
B.S., Ohio State University, 2004

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
June 2014**

Author: Paul M. Brisker

Approved by: Javier Salmeron
Thesis Co-Advisor

Robert Dell
Thesis Co-Advisor

Chad Seagren
Second Reader

Robert F. Dell
Chair, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This research creates Marine Corps Reserve Optimizer (MCRO), an optimization tool to aid Marine Forces Reserve (MARFORRES) in the task of geographically situating their subordinate units with respect to demographics. It implements an integer linear program that selects optimal locations for all candidate moving units based on the projected availability of qualified recruits in candidate areas. MCRO optimizes to (a) minimize a penalty function that measures stress with respect to demographics, and (b) minimize unit movement. Two base cases are demonstrated, one illustrating the total demographic stress with 2011 population data without allowing unit movements, and another with the projected 2036 population under the same conditions. We then allow MCRO to recommend movements, and find that (i) the relocation of 10 units reduces the number of areas experiencing the highest penalty from nine to three, and (ii) all stress can be relieved in 56 movements. Finally, we use MCRO to evaluate and quantify the demographic impact of four possible unit movements MARFORRES is currently considering.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I.	BACKGROUND AND PROBLEM DESCRIPTION.....	1
A.	MARFORRES OVERVIEW	1
B.	FSRG EFFECTS.....	2
C.	FACTORS AFFECTING THE VIABILITY OF MARFORRES UNITS	4
D.	SCOPE OF THESIS	4
II.	LITERATURE REVIEW	7
A.	CNA STUDY	7
B.	BOOZ ALLEN HAMILTON SET OF TOOLS.....	9
C.	BRAC ANALYSES.....	11
III.	MODELING OPTIMAL FUTURE DEMOGRAPHICS FOR MARFORRES.....	13
A.	ASSUMPTIONS AND PROBLEM SPECIFICATIONS.....	13
B.	MODEL FORMULATION.....	14
IV.	MCRO DATA SETS.....	19
A.	MCRC POPULATION DATA	19
B.	BAH POPULATION DATA	20
C.	RECONCILING THE DATA SETS.....	22
V.	MCRO COMPUTATIONAL IMPLEMENTATION	25
A.	MODEL INPUT FILES	25
B.	MODEL OUTPUTS.....	26
VI.	MODEL RESULTS	31
A.	MCRO BASE CASE 2011.....	31
B.	MCRO BASE CASE 2036.....	33
C.	MCRO FULL CASE 2036.....	34
D.	POTENTIAL UNIT MOVEMENT ANALYSIS	38
1.	M14163 Scenario	38
2.	M14127 Scenario	39
3.	M14404, M14411, and M14412 Scenario.....	40
4.	M01774 Scenario	41
VII.	CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK.....	43
A.	CONCLUSIONS	43
B.	CUSTOMIZATION OF TARGET RECRUITING RATIO BY AREA ..	43
C.	POPULATION DATA.....	45
D.	ADDING FACILITY AND COST DATA	47
	APPENDIX. MCRO AREAS AND SUBAREAS.....	49
	LIST OF REFERENCES.....	55
	INITIAL DISTRIBUTION LIST	57

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

Figure 1.	Planned 2010 FSRG MARFORRES restructuring, color-coded in terms of unit reorganizations, additions, deletions, and consolidations, by fiscal year, from [3].	3
Figure 2.	MCRO penalty function. The amount of penalty generated increases nearly-quadratic until 200 percent of t_a , at which point the penalty increases at a higher rate.	15
Figure 3.	Subareas in BAH population data. All circles on the map are centered on an HTC site and have a radius of 100 miles, after [17].	20
Figure 4.	The Lansing, Battle Creek, Grand Rapids, and South Bend subareas. All circles have radius of 100 miles, after [17].	22
Figure 5.	The value of the objective function decreases as the number of allowed unit movements increases. It reaches zero after 56 unit movements.	38

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1.	Example QCP data. It shows the model area, the state in which most of the area falls, the subareas that are part of the area, and its recruitable population.	19
Table 2.	Example MCRO output file data. For area a1, MCRO places units totaling 866 billets, it has a 1,134 billet target, its recruitable population is 453,695, and this yields a recruitable population to billet ratio of 523.9 (453,695 / 866).	27
Table 3.	Example Movements output file data. For example, in this instance MCRO moves unit M29063 from area a41 to area a1.	27
Table 4.	Example penalty table output file data. In this scenario, area a9 generates the highest penalty, even though it is filled in fewer increments, because of the large number of billets in the area (a9 includes New York City).	28
Table 5.	Percentage of t_a for unit billets placed in areas (2011 data). 23 areas have fewer than 80 percent of t_a billets and incur no penalty. All other areas have some penalty. The six areas over 200 percent of t_a comprise the largest penalty.	32
Table 6.	MCRO_out data for the six most demographically stressed areas (2011 population data). For example, in area a16 MCRO places units totaling 625 billets, compared to a target number (t_{a16}) of 168. Parameter t_{a16} is calculated as $67,265 / r_{a16}$, where $r_{a16} = 400$ recruitable people per billet. The actual recruitable-people-per-billet ratio for the area is $67,265 / 625 = 107.6$	33
Table 7.	Percentage of t_a for unit billets placed in areas (2036 data). 47 areas have fewer than 80 percent of t_a billets and incur no penalty. All other areas have some penalty. The three areas over 200 percent of t_a comprise the largest penalty.	34
Table 8.	Results obtained by allowing MCRO to move units to seek the highest possible reduction in penalty. This table shows that units MCRO selects for movement based on the demographic strain they are under in their current area, and the areas in which MCRO places them.	36
Table 9.	Sample M&RA data for reserve unit staffing in southeastern Virginia (model area a16). The “ON HAND” column shows the number of active Marines at the unit, and the “ASR” column shows the number of billets the unit rates, from [4].	44
Table 10.	Sample M&RA data for reserve unit staffing in upstate New York (model areas a6 and a7), from [4].	45
Table 11.	List of model areas and included subareas.	53

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

AC	active component
ARIMA	autoregressive integrated moving average
ASR	Authorized Strength Report
BAH	Booz Allen Hamilton
BIC	billet identification code
BRAC	Base Realignment and Closure
CNA	Center for Naval Analyses
CORRS	Commanding Officer's Readiness Reporting System
CSV	comma separated variable
DFAT	Demographic Forecast Analysis Tool
FSRG	Force Structure Review Group
FY	fiscal year
GAMS	Generalized Algebraic Modeling System
GFAT	GAMS File Assistance Tool
HTC	home training center
IRR	Individual Ready Reserve
M&RA	Manpower and Reserve Affairs
MARFORRES	Marine Forces Reserve
MCRC	Marine Corps Recruiting Command
MCRO	Marine Corps Reserve Optimizer
MDAT	Manpower Demand Analysis Tool
MRAT	Manpower Redistribution Analysis Tool
MOS	military occupational specialty
MSMT	Manpower Sustainability Modeling Tool
OAP	obligor alignment plan
PS	prior service
QCP	qualified candidate population
RUC	reserve unit code
SMAT	Structure Movement Analysis Tool
SMCR	Selected Marine Corps Reserve

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Marine Forces Reserve (MARFORRES) is currently conducting a large restructuring of many of its subordinate units as a consequence of directives originating from the 2010 United States Marine Corps Force Structure Review Group (FSRG). This restructuring takes several different forms, involving the creation, retirement, consolidation and/or reorganization of various MARFORRES units throughout the United States. Some of the structure changes the FSRG mandates are prescriptive in nature, but others allow MARFORRES leeway in how they decide to implement them. This research creates Marine Corps Reserve Optimizer (MCRO), an optimization model and tool to help MARFORRES make these decisions.

MCRO finds optimal locations for MARFORRES units with respect to demographic factors, specifically the projected availability of qualified 17–24 year-old high school graduates within a given area. It builds on previous efforts, mainly by Booz Allen Hamilton (BAH), which was contracted by MARFORRES to produce several tools that could describe some of the effects that unit movements can have on the mission readiness of MARFORRES units [1], [2].

We use data sourced from the Marine Corps Recruiting Command and BAH to both estimate the current available recruitable population of 84 separate areas in the United States, and their projected population through 2036. The current MARFORRES unit layout is obtained from Headquarters Marine Corps Manpower and Reserve Affairs division. These data form the bulk of MCRO’s inputs.

MCRO’s prescriptions are driven by a demographic penalty function and a movement minimization function. The former assigns non-linear penalties to areas based on the difference between the number of billets that are assigned to an area and the ideal number that should be assigned to that area (a user input). The movement minimization function takes the optimal solution from the penalty function optimization, and finds other solutions that have a similar objective function value with a minimum number of unit movements.

Two base cases are demonstrated. The first illustrates the total demographic penalty produced by the current locations of all MARFORRES units with 2011 population data, and highlights the areas that are under significant demographic stress. The second performs the same operation with the projected 2036 population numbers, showing how the demographic penalty will change over time in all areas without any unit movements. This illustrates the particular areas that are experiencing the most demographic stress.

Next, we allow MCRO to make any unit movement in order to decrease the penalty as much as possible. MCRO finds that the movement of as few as 10 units reduces the number of areas that exceed 150 percent of their target billets from nine to three. We demonstrate that MARFORRES could completely eliminate demographic stress (all areas at or below 80 percent of their target billets) with 56 unit movements.

Finally, we use MCRO to evaluate four possible unit movements MARFORRES is currently considering. Each of these cases is small, and have rather obvious conclusions based on the demographic properties of the areas involved. MCRO correctly prescribes the expected result in all cases.

LIST OF REFERENCES

- [1] Booz Allen Hamilton, "BAH_MFRSURVIAC_LRP-Modeling Workbook," unpublished.
- [2] Booz Allen Hamilton, "Manpower Analysis Portfolio of Tools," unpublished.

ACKNOWLEDGMENTS

This thesis would not have been possible without the contributions of several people.

My thesis advisors, Professor Robert Dell and Associate Professor Javier Salmeron, deserve the lion's share of credit. They were always ready to help, capable of making seemingly impossible tasks achievable, and able to provide understanding of concepts that were initially quite daunting. This work could not have been completed without their supervision.

Mr. Gerald Ormerod, LtCol Craig Ullman, and LtCol Shawn Wonderlich at Marine Forces Reserve (MARFORRES) provided all of the initial data and guidance for this work. They were always available for any necessary additional information or clarifications.

Maj Anthony Licari at Headquarters Marine Corps, Manpower and Reserve Affairs, provided another set of data needed for this project, and took diligent steps to ensure that it was comprehensible.

Mr. Joshua Mitchell, an associate with Booz Allen Hamilton, made all of the work that his company has performed in support of MARFORRES' reorganization available and did an outstanding job of explaining it.

THIS PAGE INTENTIONALLY LEFT BLANK

I. BACKGROUND AND PROBLEM DESCRIPTION

This thesis creates an optimization model (Marine Corps Reserve Optimizer, or MCRO) to aid Marine Forces Reserve (MARFORRES). The model finds optimal locations for MARFORRES units with respect to demographic factors, specifically the projected availability of qualified 17–24 year-old high school graduates within a given area. MCRO has been developed following a request by MARFORRES Capabilities Department for additional insight into restructuring requirement changes mandated by the 2010 U.S. Marine Corps Force Structure Review Group (FSRG).

A. MARFORRES OVERVIEW

MARFORRES consists of slightly more than 300 units in 47 states, the District of Columbia and Puerto Rico. The mission of MARFORRES is to “...augment and reinforce active Marine forces in time of war, national emergency or contingency operations, provide personnel and operational tempo relief for the active forces in peacetime, and provide service to the community” [1]. In large part, MARFORRES staffs its units by two methods: recruitment of eligible local prior service (PS) Marines who separated from the active component (AC) but desire continued service with MARFORRES, and recruitment of local non-PS candidates. Among junior enlisted members, non-PS recruits comprise most of the personnel in a unit, so the location of MARFORRES units in sites where they will be able to effectively meet their staffing requirements is critical.

A non-PS recruit joins a MARFORRES unit after attending recruit training for 13 weeks, usually followed by a military occupational specialty (MOS) school for 8 to 12 weeks. In some cases, the MOS school requirement can be postponed until the following summer. Marine Corps Recruiting Command (MCRC) considers the main non-PS recruiting targets to be 17–24 year-old high school graduates. MCRC keeps track of a significant amount of demographic data for all areas of the U.S. in order to support its recruiting efforts. Almost all non-PS recruits join MARFORRES on a “6 × 2” contract,

which includes six years of active drilling as a member of the Selected Marine Corps Reserve (SMCR) and two years in the Individual Ready Reserve (IRR) in an inactive status.

PS recruiting is less thoroughly planned than non-PS recruiting. Recruiting a PS Marine depends on three factors: the Marine having separated from the AC in good standing; post-separation settling in an area close enough to a reserve unit in need of the Marine's MOS; and, a desire to continue to serve. Because the intersection of these factors is somewhat rare, PS Marines comprise a far smaller proportion of MARFORRES than their non-PS counterparts [2].

The major difference between the AC Marine Corps and MARFORRES is that there are no geographic restrictions on the members of the AC force. When a recruit signs an AC contract, the Marine Corps will choose where the recruit lives for the next four years. Alternatively, a recruit joining the SMCR expects the Marine Corps to keep a unit within a certain distance of the recruit's home for the duration of the contractual obligation to MARFORRES. If MARFORRES decides to move a unit, Marines assigned to the unit are not required to move and remain with that unit. A Marine must continue to drill if still under contract and if there is another MARFORRES unit within 100 miles or within a three-hour drive from his or her residence. The requirement to drill exists even if a Marine is not properly trained to fill any of the billets at this alternate MARFORRES unit. Once initial training and MOS school has been accomplished, a reserve Marine is under no requirement to complete any further training, even if a unit change occurs. Because of this, a reserve Marine can fill a billet at a MARFORRES unit even if his or her MOS is not adequate for the billet.

B. FSRG EFFECTS

Prior to 2010, the location of MARFORRES units had been in a relatively steady state since shortly after World War II. The locations these units occupied were a factor of training requirements and then-current demographical data for the United States. There has been a significant shift in all of these data over the last 60 years, as evidenced by the Center for Naval Analyses (CNA) study commissioned by MARFORRES [2]. The 2010

FSRG affected the location and mission of approximately 25 percent of units in MARFORRES [3]. Convened as a planning group for “right-sizing” the active and reserve components of the Marine Corps, the FSRG laid out a plan for MARFORRES to reorganize, add, delete and/or consolidate a significant portion of its subordinate units between fiscal years (FYs) 2012 and 2017 (see Figure 1). The decisions made during the FSRG most drastically affected the ground and logistics combat elements of MARFORRES. Among other changes, the FSRG eliminated one infantry regimental headquarters (“Inf Regt HQ” in FY13; see Figure 1), two infantry battalions (“AT Bn” and “Infantry Bn” in FY12-14), and several logistics units (“Supply Bn,” “Maint Bn,” “4th LSB,” and “6th MT Bn,” all in FY13). The implementation of the 2010 FSRG is currently about 70 percent complete, and is planned to finish in fiscal year 2017.

Reserve Component FSRG Plan of Action and Milestones

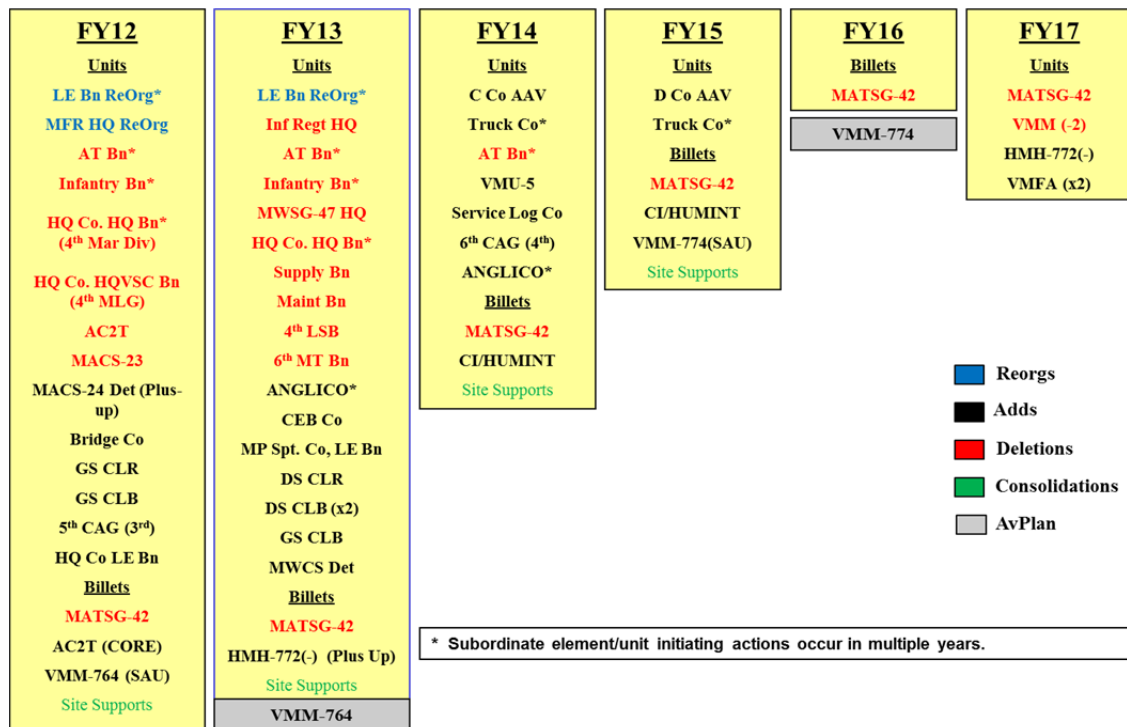


Figure 1. Planned 2010 FSRG MARFORRES restructuring, color-coded in terms of unit reorganizations, additions, deletions, and consolidations, by fiscal year, from [3].

C. FACTORS AFFECTING THE VIABILITY OF MARFORRES UNITS

Manpower and Reserve Affairs (M&RA) keeps track of several metrics of reserve unit “health” [4]. According to M&RA’s data, there are a significant number of units that are not performing well at their current locations, in comparison to other units. A sample of these metrics includes:

- The percentage of Marines currently drilling at the unit in comparison to the unit’s authorized strength [4].
- The billet identification code (BIC) match rate. This metric is the percentage of the unit’s billets that are being filled by a Marine of the correct rank and correct MOS. As previously noted, billets at MARFORRES units need not be filled by Marines of the correct rank and/or MOS; however, the effectiveness of the unit without a high proportion of BIC matches is questionable [4].
- The 12-year attrition percentage. This metric is the portion of non-PS enlisted Marines who do not complete their 6 × 2 contract over a 12-year window [4].
- The obligor alignment plan (OAP) rate. This metric is the percentage of Marines at a given MARFORRES unit who continue to remain with their unit beyond completion of their 6 × 2 contract. Obligor is a general term for MARFORRES Marines who are still under contract [4].
- PS Marines. Each MARFORRES unit allocates a certain number of its billets toward recruiting Marines who completed an AC contract, separated from the AC in good standing, and are willing to continue their service as a part of MARFORRES. It is ideal if these Marines are BIC matches for billets the unit has, but is not required [4].

The relative importance of the above metrics is subject to some debate. However, anecdotal evidence suggests that ability to recruit PS Marines is the least important, due to the fact that they are not historically likely to volunteer.

D. SCOPE OF THESIS

As mentioned previously, the changes to MARFORRES mandated by the FSRG have been almost completely implemented. Because of this, MCRO is a tool for the future. In today’s fiscal environment, it is expected that the military (and MARFORRES in particular) will again have to reorganize in order to cut costs and streamline operations.

MCRO gives decision makers a tool that is simple to use, quick in operation, and provides useful insights for future restructuring and/or reorganization of MARFORRES in terms of placing units where they are most likely to succeed. MCRO does not stand alone; rather, it provides a set of possible changes to MARFORRES unit locations subject to constraints based on demographic data and other user inputs. Any MCRO output should be subjected to close scrutiny prior to implementation, particularly in terms of the potential costs of the enterprise. The real-world MCRO data is not encyclopedic, is bound to change over time, and should be updated prior to use.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LITERATURE REVIEW

MARFORRES commissioned both the CNA and Booz Allen Hamilton (BAH) to perform studies in support of its FSRG reorganization. As such, these are the two primary sources of literature reviewed for this thesis. Another source is Base Realignment and Closure (BRAC) projects implemented over the last few decades, which is similar to the reorganization MARFORRES has executed.

A. CNA STUDY

“Demographic Dynamics of the Reserve Force Laydown,” published in July 2011, is CNA’s major work in support of addressing the problem of FSRG reorganization [2]. Commanding General, MARFORRES, commissioned this study in order to analyze how demographic trends within the U.S. impact the ability of MARFORRES to recruit personnel for local reserve units.

The CNA analysis is fairly exhaustive. The authors illustrate how shifting demographics within the U.S. have made it difficult for some MARFORRES units to stay manned. The study also addresses the various recruiting problems across the type of reservist (whether non-PS or PS), junior enlisted, staff non-commissioned officers and officers. Some of the trends they analyze are at the county level; others are simply regional (divided into nine regions across the U.S.) [2].

The summary and conclusions of the report make five general observations about the issues that MARFORRES faces in staffing its units:

- With respect to population demographics, some areas of the U.S. are quantifiably better than others in terms of recruitable persons. In the areas that are better, MARFORRES units usually, but not always, have higher staffing rates. In the areas that are worse, some units may perform well while others may not. There does not appear to be a relationship between the units that perform well or poorly in these areas that depends exclusively on demographic considerations [2].
- In broad terms, the study’s second conclusion is an extension of the first. The fact that an area has a large recruitable population does not mean that a unit in that area must perform well [2].

- The third conclusion has been, in a sense, overtaken by events. The authors observe that comparing the actual number of active SMCR Marines at a given MARFORRES unit with the number of active SMCR Marines they are supposed to have has been challenging, in a historical sense, because MARFORRES did not have a strict table of organization for all of its units. MARFORRES has since implemented this through the BIC system, and allocated a certain number of BICs to each reserve unit, so this should not be a problem in the future. However, it does present a significant challenge regarding any historical data for a given unit, because while the data regarding the number of Marines they did have may be on record, the number of Marines they should have had at that time is unknown [2].
- The fourth conclusion delves into what the authors think are other factors that affect the ability of individual reserve units to meet their staffing goals. They include, inter alia, the type of unit, proximity to other MARFORRES units, the local population's predilection toward service, etc. Based on the demographic trends the authors observe at the time, they believe that MARFORRES should "...investigate shifting some units in the Northeast and North Central regions of the United States to locations in the West and South..." The analytical method used to support this recommendation is not clear; however, the demographic data presented does seem to support this conclusion. The authors also make a recommendation that MARFORRES considers placing units in areas where there is a higher likelihood that persons with certain skillsets already reside [2].
- Finally, the authors observe that recruiting PS Marines to participate in MARFORRES is extremely challenging. The authors use data showing the addresses of all Marines in the IRR. These Marines have completed their active duty or reserve contractual obligations and are under no requirement for further service, but are eligible to join a MARFORRES unit if they so choose. There are very few MOS and pay grade matches to local reserve units across the IRR. This problem is especially difficult for the company-grade officer billets, which leads to a recommendation that MARFORRES continues its Officer Candidate Course-Reserve program as a way to continue bringing company grade officers into MARFORRES [2].

In conclusion, the CNA study is a thorough evaluation of the demographic situation facing MARFORRES, but lacks any formal method for taking the results of the analysis (presented mainly by way of charts, maps and graphs) past a general recommendation to move units "west and south" [2].

B. BOOZ ALLEN HAMILTON SET OF TOOLS

The BAH analysis of the FSRG reorganization is significantly different from the CNA study. Rather than studying demographic trends and making broad recommendations, BAH's work focuses on producing Microsoft Excel-based tools [5] that could be of immediate use to MARFORRES decision makers. BAH's work has produced five of these tools: the Manpower Sustainability Modeling Tool (MSMT), the Demographic Forecast Analysis Tool (DFAT), the Structure Movement Analysis Tool (SMAT), the Manpower Demand Analysis Tool (MDAT), and the Manpower Redistribution Analysis Tool (MRAT) [6], [7]. Each tool is accompanied by a document that describes the tool's methodology, inputs and outputs. It should be noted that three of the five BAH tools are oriented on describing the immediate effect of MARFORRES structure changes, and while the tools are extremely detailed in execution, they do not attempt to optimize the structure of MARFORRES in any way. The function of each tool is described below.

The MSMT takes as input proposed changes to MARFORRES structure in the form of unit realignments, activations or deactivations, while holding all other units in their current location. It uses the input to produce two reports. The first describes the likelihood that a location can support the proposed change and the expected available manpower for that location over the next 25 years (from 2011). The second produces a by-year analysis of the projected manpower available for recruitment and the predicted recruiting success for each location, given the changes made. While MSMT is capable of evaluating and describing the effects of user-inputted changes, it does not have the capability of prescribing those changes [6].

The DFAT allows the user to select two areas as inputs, and produces two side-by-side tables that show both the historical population of each area and its forecasted demographics. It uses the U.S. Census Bureau's data for the historical part, and then uses the same data to forecast the future population through 2036 based on an autoregressive, integrated, moving average (ARIMA) model. While DFAT does not make recommendations per se, the tool provides a quick snapshot comparison of past and possible future demographics for a pair of potential MARFORRES unit sites [7].

The SMAT takes user input in the form of a unit proposed for moving, and an area to receive the moving unit. Following those inputs, the tool produces a series of tables that describe the effects of the proposed move in terms of BIC mismatches created by the move. This information is in terms of the personnel who are currently within the MARFORRES driving distance rules for the proposed site. As might be inferred, this tool is dependent upon a significant amount of data, including the contract length information, MOS, rank and address of every drilling member of MARFORRES. As such, the tool is extremely susceptible to becoming outdated unless that information is updated on a regular basis. However, it provides a current snapshot of how a given move would immediately impact the mission readiness of the moved unit, based on the number of personnel in the area who could potentially join that unit if it were moved [7].

The MDAT fills a purpose somewhat related to the SMAT. It provides a snapshot of how, if a given unit is removed from an area, those personnel who had been a member of the moved unit could be reallocated to fill billets at other nearby MARFORRES units. This analysis is done both in terms of the commute time and distance to the other units, as well as whether or not the personnel are a match for any of the BICs at the nearby units. Like the SMAT, this tool depends on up-to-date data to be correct and fully effective [7].

The MRAT is, to some extent, a complementary tool to the MDAT. While the MDAT considers the perspective of possibilities for Marines whose units have departed their area, the MRAT analyzes the same situation from the potential gaining unit's perspective. In other words, it considers another MARFORRES unit in close proximity to the unit that moved, and identifies the Marines left behind by that unit that would be within commuting distance of the potential gaining unit. It produces a table that displays their obligor status, whether or not they would require lodging during were they to join the new unit, and their MOSs [7].

Overall, the BAH tools are an impressive set of work, and it is recommended that they be updated as a complement to MCRO. The BAH tools are capable of distilling a vast quantity of information about the short-term impacts of unit movements into concise, easily understandable outputs. MCRO adds to their capabilities by providing

prescriptions that consider the long-term impacts of simultaneous movements for all units under study in demographical terms, via mathematical optimization.

C. BRAC ANALYSES

There are many BRAC analyses available, several of which have been developed by Naval Postgraduate School faculty and students (e.g., [8] and [9]). In general, the purpose for these analyses has been to minimize costs across facilities and units, while still fulfilling all mission requirements. The typical BRAC analysis cost timeline is 20 years. As previously stated, since the main focus of the BRAC analyses is on AC forces and bases, their usefulness in the context of this work is somewhat limited. However, the parallels with BRAC are potentially useful in terms of facilities and timelines. Active and reserve forces alike are tied to the facilities that they use, and the cost factors associated with building new facilities, closing old ones, re-purposing them, sharing them across units, or other such changes are largely similar. This information may be more useful in an expansion of this work that considers optimization subject to these factors.

THIS PAGE INTENTIONALLY LEFT BLANK

III. MODELING OPTIMAL FUTURE DEMOGRAPHICS FOR MARFORRES

This chapter describes the assumptions used to develop MCRO, the problem specifications and its mathematical formulation. The MCRO software implementation is addressed later in this thesis.

A. ASSUMPTIONS AND PROBLEM SPECIFICATIONS

While MCRO could theoretically recommend moves for all MARFORRES units to new locations in line with the best projected demographics, it must also be capable of considering several limiting factors:

- First, some MARFORRES units cannot be moved at all, or could potentially only be moved to a small subset of alternate locations, because they require a specific type of facility as a home training center (HTC). An example would be an aviation unit of any sort; it is evident that a unit of this type must be placed on a military airfield in order to be able to perform its mission.
- The proximity of adequate training facilities must also be considered. It is inadvisable, for instance, to move an artillery unit to a location where there is no adequate artillery range within a reasonable traveling distance, even if there is a perfectly acceptable HTC for the unit at that location.
- Finally, relationships between units must be considered. If one unit's mission is dependent upon the support of another unit (for instance, a maintenance unit and a truck company), then these units must remain collocated.

One of the user inputs is the target ratio of recruitable population in each area a to the amount of MARFORRES structure (i.e., number of billets) placed into the area. This is referred to as r_a in the model formulation, described in Section B. This is a topic that may be worthy of research in and of itself. As the CNA study shows, throughout the U.S. there are some areas in which MARFORRES has no problem keeping units staffed, because the population in the area well supports the units placed there. Other areas perform quite poorly in supporting units, even with a seeming plethora of recruitable individuals. To date, no exhaustive analysis of the underlying reasons for this

phenomenon has been attempted, the result of which might well be a cogent estimate of how much structure MARFORRES could place in each area and reasonably expect it to remain staffed at acceptable levels. However, the data mentioned in Chapter I (as factors affecting the viability of reserve units) are examples that apply to this problem. Even without a rigorous analysis, a user familiar with the performance of MARFORRES units according to these data can make a reasonable estimate of what the ratio should be for each area.

An assumption made in MCRO is that short-term effects on the mission-readiness of a moved unit are negligible. This is certainly not always the case: a moved unit could be short-handed in MOS-qualified personnel for some time after it is relocated. However, the BAH tools already do an extremely thorough job of quantifying the shortfalls that are associated with moving units in the near-term (the SMAT and MDAT, in particular, are designed specifically for this purpose). Given that a typical MARFORRES unit experiences high turnover in a six-year span (due to the typical 6×2 contract structure previously mentioned), it is considered extremely likely that a moved unit will be fully staffed within that time if it is moved to an area with favorable demographics. Because MCRO is mainly concerned with a much longer timeline, the short-term effects of moving the units are not considered, except to limit the total number of unit moves and the allowed candidate moves.

B. MODEL FORMULATION

Before describing MCRO's formulation in detail, it is useful to the reader to understand how the model's "penalty function" operates. Much of the structure of the model is dependent on the penalties, because the first of MCRO's two objective functions exists solely to minimize the penalty that is incurred as a result of all unit placements.

Once the user inputs the values of r_a for area a into MCRO, those are used to calculate the target number of billets to assign to each area (t_a in the formulation). MCRO assigns billets to each area in increments. The first increment allows up to 80 percent of t_a to be placed there without incurring any penalty. The second increment allows an

additional five percent of t_a , by paying a small penalty per billet in that increment, and so on. Figure 2 illustrates how the penalty MCRO generates in an area increases as more billets are assigned to the area.

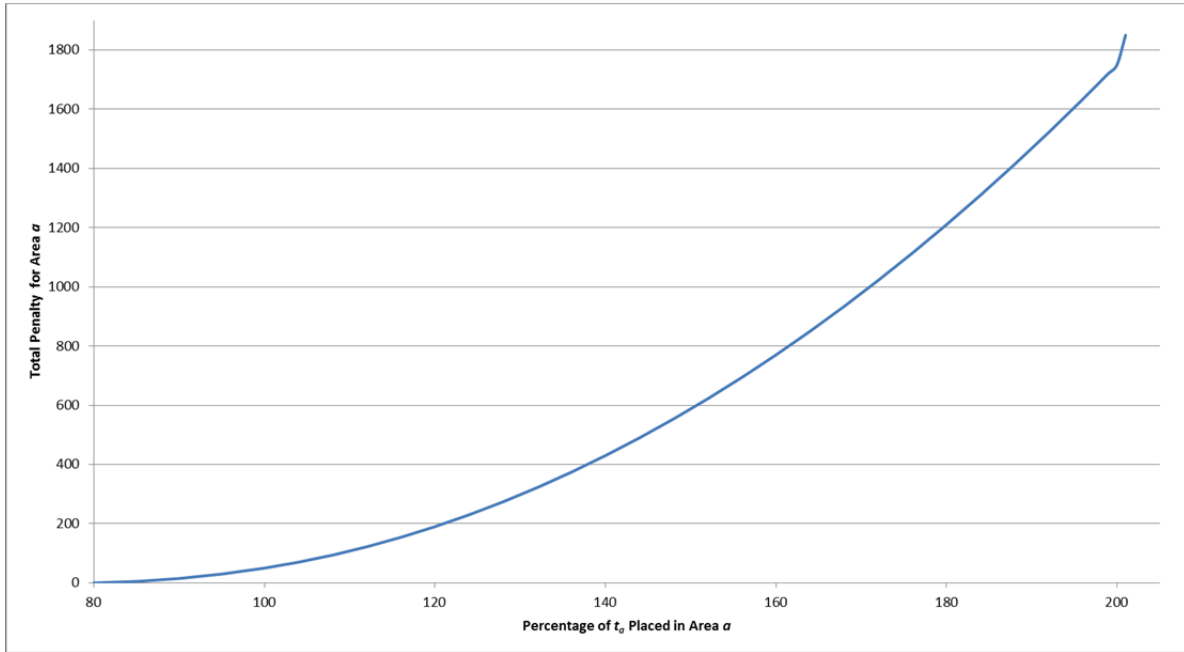


Figure 2. MCRO penalty function. The amount of penalty generated increases nearly-quadratic until 200 percent of t_a , at which point the penalty increases at a higher rate.

The reasoning behind constructing the penalty function in this manner is to allow MCRO to place units nearly anywhere, but to force it to incur a high penalty for doing so if it exceeds a certain percentage of t_a . The implicit assumption is that it should be fairly easy for a unit (or group of units) to recruit 80 percent of their staffing goals in a given area, which is why no penalty is paid up to that level of staffing. However, recruiting is more difficult as more units are located in the area. In other words, the penalty function is reflecting a “risk” of failing to recruit enough personnel for the structure placed in the area. We model the amount of risk as a piecewise-linear function across all increments with linear increase by increment, which approximates a quadratic penalty function. The user may employ different penalties or percentages, as addressed in the formulation below.

MCRO conducts two optimization runs. The first, called the “Demographics Model,” optimizes with respect to the penalty function described above. A number of MCRO sample runs indicate that, in some circumstances, there can be more than one solution with the same optimal objective function value, and that it is possible for the solutions to differ in the number of unit moves. Because moving units is costly, if roughly the same benefit can be attained in demographic terms by moving fewer units or fewer billets, the latter is likely to be a better real-world solution. The second optimization, called the “Moves Model,” finds a solution that minimizes either the number of units moved or number of billets relocated.

Given that we explicitly ignore constraints such as facility requirements, costs, etc., the resulting model is relatively straightforward. For future reference and where appropriate, we include the name of the MCRO input file in parentheses. Below is the complete formulation:

Indices and sets:

$u \in U$	set of units (Units)
$a \in A$	set of areas in which units can be placed (Areas)
$i \in I$	set of increment intervals in which units are placed in an area with a penalty (Penalty_&_Percentage)
$a_u \in A$	initial area a for unit u (Current_Unit_Areas)
$(u, u') \in G$	subset of units (u, u') where unit u must be collocated with unit u' (Bound_Units)
$(a, u) \in F$	subset of pairs (a, u) where unit u may be placed in area a (Future_Unit_Areas). $(a, u) \notin F$ if $(u, u') \in G$ and $(a, u') \notin F$

Data [units]:

s_u	size of unit u [number of billets] (Unit_Data)
$people_{a,i}$	maximum number of billets able to be placed in area a , in increment i ($people_{a,i} = per_i \times t_a$, where $t_a = p_a / r_a$) [number of billets]
p_a	recruitable population of area a in a given year [people] (Area_Data)
r_a	population-to-structure ratio for area a [people/billet] (Area_Data)
t_a	target recruiting total for area a ($t_a = p_a / r_a$) [number of billets]
per_i	fraction of t_a to be added in increment i [billets/billets] (Penalty_&_Percentage)

$penalty_{a,i}^D$	penalty for deviation from t_a in area a , in increment i used in the Demographics Model [penalty/billet] (Penalty_&_Percentage)
$penalty_{a,u}^M$	penalty for moving unit u to area a for the Moves Model (we use penalty 1 to count number of moves, or penalty s_u to count billets moved) [penalty/billet]
n	number of unit moves allowed [unitless]
\bar{Z}^D	target for Demographics objective for the Moves Model [penalty/billet]
ε	small factor to break ties for the Moves Model [unitless]

Decision variables [units]:

$X_{a,u}$	1 if unit u is placed in area a , and 0 otherwise [unitless]
$Rpos_{a,i}$	billets placed in area a , in increment i [number of billets]
Z^D, Z^M	objective values for Demographics and Moves Models, respectively [penalty/billet and moves, respectively]

Demographics Model Formulation:

Minimize:

$$Z^D = \sum_{a \in A} \sum_{i \in I} penalty_{a,i}^D Rpos_{a,i} \quad (1)$$

subject to:

$$\sum_{a|(a,u) \in F} X_{a,u} = 1 \quad \forall u \in U \quad (2)$$

$$\sum_{u|(a,u) \in F} s_u X_{a,u} \leq \sum_i Rpos_{a,i} \quad \forall a \in A \quad (3)$$

$$\sum_{(a,u) \in F | a \neq a_u} X_{a,u} \leq n \quad (4)$$

$$0 \leq Rpos_{a,i} \leq people_{a,i} \quad \forall a \in A, i \in I \quad (5)$$

$$X_{a,u} = X_{a,u'} \quad \forall (u, u') \in G \quad (6)$$

$$X_{a,u} \in \{0,1\} \quad \forall (a,u) \in F \quad (7)$$

Moves Model Formulation:

Minimize:

$$Z^M = \sum_{(a,u) \in F | a \neq a_u} \text{penalty}_{a,u}^M X_{a,u} + \varepsilon Z^D \quad (8)$$

subject to:

$$Z^D \leq \overline{Z}^D \quad (9)$$

(1)–(7)

Chapter IV details the data inputs for MCRO. A brief explanation of the formulation follows.

- Equation (1) is the objective function of the Demographics Model. The objective function value is the total amount of demographic penalty incurred across all areas.
- Constraint set (2) ensures that each unit is assigned to only one area.
- Constraint set (3) measures how many billets are in each increment in each area.
- Constraint set (4) limits the number of unit movements to the input parameter n .
- Constraint set (5) limits the number of billets in each increment i and area a , and establishes non-negativity.
- Constraint set (6) ensures units are colocated when such a requirement exists.
- Constraint set (7) declares $X_{u,a}$ to be binary.
- Equation (8) is the Moves Model objective function where, depending on the movement penalty, $\text{penalty}_{a,u}^M$, we may minimize the number of moves or the total billets being moved. (In our computational results, we have only exercised the former option, i.e., minimizing the number of unit moves.) The second term of the objective ensures that placement of units still occurs orderly in the increments used in the Demographic Model.
- Constraint (9) is for use with objective (8). Typically, \overline{Z}^D is set to the optimal objective function value of the Demographics Model Z^{D*} (or Z^{D*} multiplied by a number slightly greater than one).

IV. MCRO DATA SETS

This chapter discusses the two data sets used to model the current and future populations in the areas of interest to MARFORRES. The two data sets differ significantly in their construction and reconciling them has been one of the major challenges to implementing MCRO. The MCRC data includes only 2011 population data, while the BAH data begins in 2011 and ends in 2036.

A. MCRC POPULATION DATA

MCRC keeps population data for its recruiting regions in areas delineated by state and/or county boundaries. These data are called the Qualified Candidate Population (QCP). The numbers in the QCP data reflect the population of 17- to 24-year-old male high school graduates for the area in question, who are the primary source of recruits for MARFORRES units. Table 1 shows a sample of the areas in the QCP data [3].

Area	State	Included Cities	Recruitable Population
a1	PA	PHILADELPHIA/FOLSOM/WILLOW GROVE/ALLENTOWN/WILMINGTON, DE	324,462
a2	PA	HARRISBURG/READING	129,026
a3	PA	PITTSBURGH/JOHNSTOWN/EBENSBURG	127,360
a4	OH	DAYTON/CINCINNATI/COLUMBUS	194,161
a5	OH	CLEVELAND/AKRON/VIENNA/ERIE, PA	214,486

Table 1. Example QCP data. It shows the model area, the state in which most of the area falls, the subareas that are part of the area, and its recruitable population.

The 84 areas in the QCP data are the same areas referred to in the MCRO formulation. It is important to note that the QCP data does not share populations between areas; in other words, the recruitable population of an area belongs exclusively to that area.

B. BAH POPULATION DATA

The BAH DFAT, as previously mentioned, uses population data generated by an ARIMA model to predict how populations around certain sites will change over time (the tool's data start in 2011 and end in 2036). However, this data set does not take any state or county boundaries into consideration. Given that a recruit is considered eligible to join a MARFORRES unit if the recruit's residence is within 100 miles of the HTC that unit occupies, the BAH data uses the population within 100 miles of all current and potential future HTC sites that MARFORRES asked to consider. As such, there are about 200 areas (hereafter referred to as subareas). For instance, the single area in the MCRC data, including Philadelphia in Table 1, is composed of seven subareas in the BAH data. Figure 3 shows the subareas used in the BAH data [10].

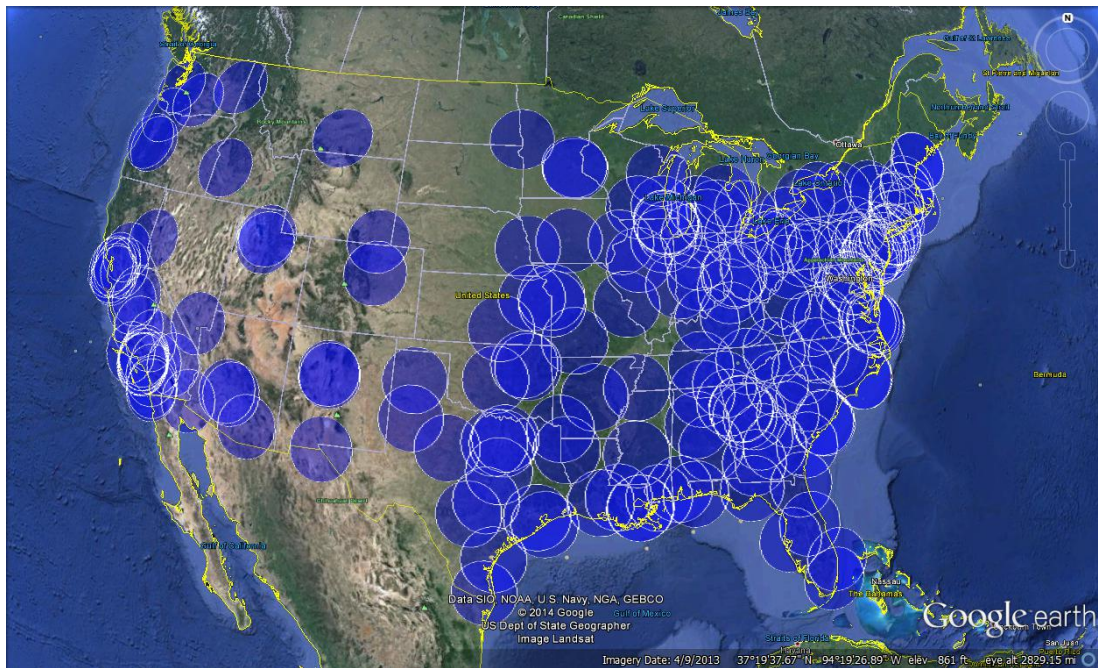


Figure 3. Subareas in BAH population data. All circles on the map are centered on an HTC site and have a radius of 100 miles, after [17].

The BAH data presents some challenges for its use in this analysis. As Figure 3 shows, there is significant overlap among the subareas in certain regions of the country. This problem is most significant in the northeastern U.S., where there are, in some places, as many as 30 subareas covering the same geographical territory. BAH did not take these intersections into consideration when building their data set, so in cases where an intersection between two or more subareas exists, all people in the intersection are counted for all intersecting subareas. Additionally, some of the major population centers throughout the U.S. are geographically situated in such a way that the BAH method of counting population skews the population estimates for a given subarea substantially. As an example, South Bend, Indiana, is within 100 miles of Chicago, resulting in the BAH data including a significant portion of the population of Chicago in the estimate for South Bend. However, South Bend is part of another area in the MCRC data that includes three population centers in southern Michigan—none that are within 100 miles of Chicago (see Figure 4). This effect skews the population of South Bend much higher in relation to the other population centers in its area than it would otherwise be (according to U.S. Census data, South Bend is the third-most populous city among the four cities in its area, instead of being the most populous as indicated in the BAH data [11]).

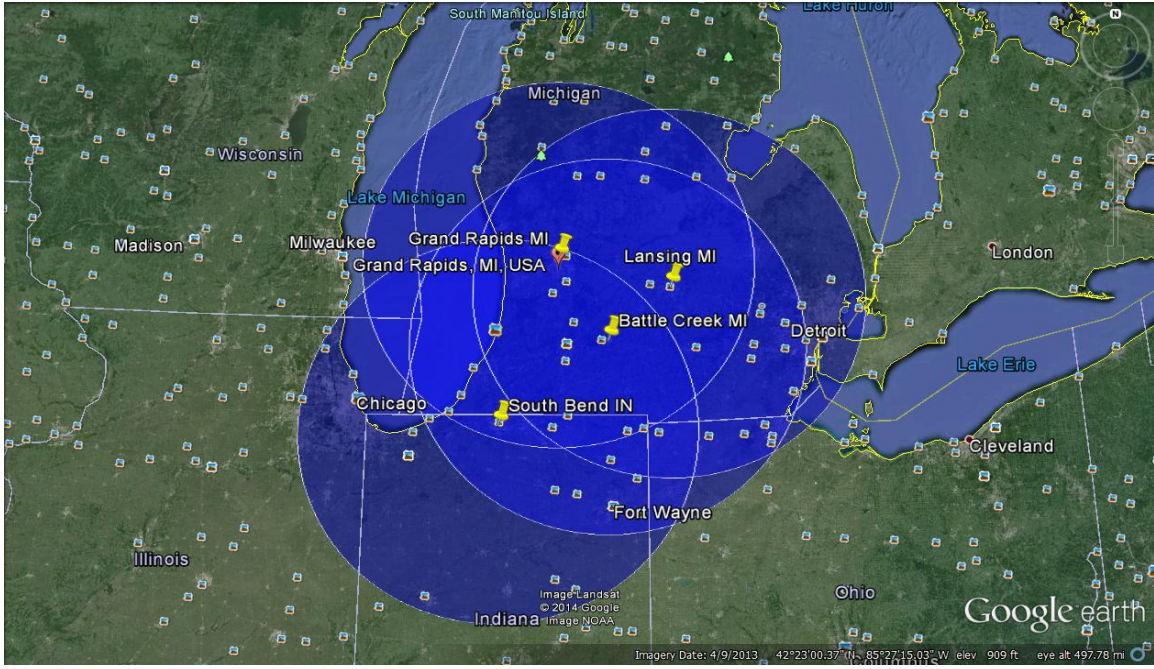


Figure 4. The Lansing, Battle Creek, Grand Rapids, and South Bend subareas. All circles have radius of 100 miles, after [17].

C. RECONCILING THE DATA SETS

After considering several possible courses of action to de-conflict these two sets of data, this thesis treats the population numbers from the QCP as a “net” recruitable population for each area a , $NetPopulation_a$, and considers the subarea s populations from the BAH data as “gross” populations, $GrossPopulation_s$, which must be scaled in order to fit the net population for the subarea, $NetPopulation_s$. Let a be the QCP area where BAH’s subarea s is located. Let S_a be the subset of subareas in area a . The scaling method to calculate $NetPopulation_s$ is performed using Equation (10):

$$NetPopulation_s = \frac{GrossPopulation_s}{\sum_{s \in S_a} GrossPopulation_s} NetPopulation_a \quad (10)$$

The estimated growth factors by subarea (based on the ARIMA model used by BAH) can now be used to project how the net populations of the MCRC-derived areas

are expected to change over time. The model's baseline runs are conducted with the predicted recruitable populations for year 2036 in all areas.

It is important to note that the net populations for these subareas are not meant to reflect the actual populations of the subareas. Rather, they are a relative estimate of the ability of these subareas to recruit within their area, and possibly from outside their area as well. For instance, while the recruitable population of South Bend is somewhat skewed by its proximity to Chicago, it is in fact possible that a unit in South Bend could recruit from that city or its suburbs, particularly from the eastern side. This algorithm weights South Bend with respect to that fact, and as such, among the four subareas within its area, South Bend has the highest recruitable population. However, this comparison is only valid for subareas within a given area; it is not generalizable as a comparison between subareas in different areas. There are several reasons for this, among which two are particularly relevant: the number of subareas within one area varies substantially, and the net recruitable populations of adjacent areas can be vastly different.

THIS PAGE INTENTIONALLY LEFT BLANK

V. MCRO COMPUTATIONAL IMPLEMENTATION

We use the Generalized Algebraic Modeling System (GAMS) [12] software to implement MCRO and solve it using CPLEX [13] on a Lenovo Y580 laptop computer. The computer has an Intel Core™ i7 3630-QM quad-core processor with eight GB of RAM and 2.4 GHz processor. A typical instance of MCRO has approximately 28,000 decision variables (26,000 of which are binary) and about 400 constraints. Typical time to achieve an optimal solution varies according to the number of unit movements being considered. In simple cases, the run time is a few seconds, but it can take 30 or more minutes in cases where many unit movements are considered simultaneously.

A. MODEL INPUT FILES

We use comma-separated variable (CSV) data sheets to input MCRO data into GAMS. In addition to these, a Microsoft Excel [5] workbook titled the GAMS File Assistance Tool (GFAT) is a companion file useful to facilitate the construction of some of these CSV inputs. The part each plays in solving MCRO is described as follows:

Areas: This is a single-column input of the 84 areas under consideration in the model, labeled as “a1” through “a84”. The specific map regions that each of these areas corresponds is in the GFAT and the appendix.

Area_Data: This file contains three columns of information: the area in question, the predicted recruitable population for that area in the year under consideration, and the target ratio of recruitable population to structure placed in the area (r_a from the formulation). The default value selected for r_a for all areas is 400 recruitable personnel per billet placed in the area, but this can be adjusted for particular areas by the user.

Units: Similar to the Areas file, this is a single column of data that represents the Reserve Unit Code (RUC) number for all MARFORRES units. The specific units to which each number corresponds is also shown in the GFAT.

Unit_Data: This file contains the list of units by RUC, coupled with the number of billets associated with each unit from the Authorized Strength Report (ASR). The complete ASR is in the GFAT.

Current_Unit_Areas: This file is a matrix, which contains as its rows all MARFORRES units and all of the areas as its columns. If a given unit is

within a given area, there is a '1' in that row and column intersection; otherwise, there is a blank space. Because there are many units in some areas and no units in others, the column sums range from 0 to 27 (there are currently 27 MARFORRES units in a76, the area designation for southern California), but the row sums all must equal one (a unit cannot be in more than one area). MCRO uses the data in this matrix to compare a unit's initial location to its final location following optimization.

Future_Unit_Areas: This file has the same format as the **Current_Unit_Areas** matrix, but this matrix constrains the possible future locations of a unit. The user places a '1' in the column for any area to which the unit corresponding to that row may move.

Penalty_&_Percentage: MCRO uses the data in this file to determine the shape of the Demographics Model penalty function. It should not be adjusted by the user unless the he or she fully understands the ramifications of changing penalties.

Bound_Units: This file contains pairs of units that must remain collocated. The user places the unit RUCs of bound units side by side in the first two columns of the file.

B. MODEL OUTPUTS

GAMS can be configured to create any number of reports in CSV or text documents. The model currently produces three: a text file entitled "MCRO_out," and two CSV files entitled "Movements" and "Penalty_Table." Table 2 shows a sample of the MCRO_out file. The first line in the file shows the demographics model objective function value for the optimization after the Moves Model. Following that line, the file contains five columns of data and results from the model run. The first column specifies the area to which the subsequent data corresponds. The second column, called "assigned," contains the total number of MARFORRES billets that MCRO recommends be placed in that area. The third column, "population," is the total recruitable population in that area, corresponding to the number input into MCRO through the Area_Data file. The fourth column, "ratio," is the number from the population column divided by the number from the assigned column, and represents the achieved demographic ratio for the area. The final column, "target," represents parameter t_a for the area, which as earlier described is the number of billets MCRO calculates that the area should receive based on the area's population and r_a .

Objective value is 187175.02				
area	assigned	target	population	ratio
a1	866	1,134	453,695	523.9
a2	379	492	196,708	519.0
a3	580	424	169,629	292.5
a4	491	637	254,648	518.6
a5	470	631	252,504	537.2

Table 2. Example MCRO output file data. For area a1, MCRO places units totaling 866 billets, it has a 1,134 billet target, its recruitable population is 453,695, and this yields a recruitable population to billet ratio of 523.9 (453,695 / 866).

Table 3 contains an example of the output contained in the Movements CSV file. The first column, “Unit,” contains the RUC number of the unit MCRO selected to move. The second and third columns, “From” and “To,” show the areas from which and to which MCRO moved that unit, respectively.

Unit	From	To
M29063	a41	a1
M22429	a41	a51
M01149	a76	a58
M14031	a76	a62
M21441	a76	a43

Table 3. Example Movements output file data. For example, in this instance MCRO moves unit M29063 from area a41 to area a1.

Table 4 displays a sample of the data from the Penalty Table file. The areas in this table are all generating penalty in the model within the first seven increments. The first

column lists the areas, and the subsequent columns are the increments into which billets are placed in those areas. Where there are numbers in the columns for increments 2 and higher, it indicates that the model placed more than 80 percent of t_a into that area, and that the model is producing a penalty for all of the billets in those increments. The rightmost column shows the total penalty accrued across these increments for each area.

	Increments (% of t_a) and Penalty/Billet (shown in italics)						Area Penalty
	(80–85]	(85–90]	(90–95]	(95–100]	(100–104]	(104–108]	
Area (a)	1.0	2.0	3.0	4.0	5.0	6.0	
a9	137.9	137.9	39.1				531.0
a12	6.8	6.8	6.8	6.8	5.4	0.7	99.2
a14	9.6	9.6	9.6	9.6	6.7		129.6
a26	18.2	18.0					54.3
a27	14.6	14.6	14.6	10.5			129.5
a45	6.9	6.9	6.9	6.9	5.5	1.9	107.6
a79	4.9						4.9

Table 4. Example penalty table output file data. In this scenario, area a9 generates the highest penalty, even though it is filled in fewer increments, because of the large number of billets in the area (a9 includes New York City).

The data in Table 4 is very revealing. The first increment (not shown) corresponds to up to 80 percent of t_a and incurs no penalty. Increments 2–5 (columns 2 to 5) correspond to an additional 5 percent each of the value of t_a , and all increments shown from increment 6 on are an additional 4 percent of t_a . Therefore, increment 5 represents up to 100 percent of t_a , while increment 7 represents up to 108 percent. For example, area a9 is receiving the full complement of its 2,521 billets within the first four increments, and generates some penalty in increments 2, 3, and 4. The penalty in increment 2 is 137.9 billets placed in that increment multiplied by the penalty associated with the increment (one penalty unit per billet). Increment 3's penalty is two, and increment 4's penalty is three, so a9 incurs a penalty of $(137.9 \times 1.0) + (137.9 \times 2.0) + (39.1 \times 3.0) = 531.0$. Parameter t_{a9} is 2,758 billets, so based on the increment intervals MCRO distributes the 2,521 billets as follows: 2,206.1 billets in a9's increment 1 (without penalty), 137.9 billets in increments 2 and 3, along with 39.1 in increment 4. The calculations are similar for all other areas.

The Penalty Table file can thus serve as a quick guide to understand the areas that are most demographically stressed. The more increments MCRO must use to fill the billets into a given area, the higher the penalty incurred.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. MODEL RESULTS

This chapter discusses results for several MCRO prescriptions motivated by scenarios MARFORRES is currently considering. It also includes a benchmark showing demographic penalties for the current MARFORRES unit locations with the 2011 population data, and with the 2036 population data if no units move. We highlight the units incurring the most demographic penalty. Using MCRO, we evaluate several unit movements MARFORRES is currently considering in demographical terms.

The reader should be aware that MCRO objective values only have meaning relative to a base case. The model must first be run on any scenario without allowing any unit movements, so as to establish how much penalty the current unit configuration is generating (the base case). With this number in hand, MCRO may run any alternative scenario. The objective function value for a scenario will be the same as the base case if MCRO cannot find a demographically superior location for units, or less if it does. The only circumstance in which MCRO produces an objective value greater than the base case is if MCRO is not allowed to leave a unit in place, and must therefore move it to an area that is worse than the base case.

A. MCRO BASE CASE 2011

This scenario has the following attributes:

- All units are held to their current location.
- There are no units currently in areas a8 (Glenville/Albany, NY), a25 (Jackson, MS), a33 (Tallahassee, FL), a54 (Lafayette, LA), a68 (Saginaw, MI), or a77 (Reno, NV).
- It uses net population data from the 2011 QCP.
- The value of r_a is set to default value of 400 for all areas.

Table 5 shows the level areas are demographically penalized under the current MARFORRES unit layout. This scenario produces a very large objective function value (113,225). The reason for this is that there are a large number of areas that are exceeding their calculated t_a value by a significant margin. Under these constraints, MCRO areas

a16 (around Norfolk, VA), a18 (Lynchburg and Roanoke, VA), a19 (Quantico, VA), a24 (New Orleans, LA), a31 (Albany, GA), and a80 (Billings, MT) have the highest penalty tier. In addition to these six areas, another 30 of the 78 areas are above 100 percent of t_a calculated for the area using the 2011 population. At the same time, 23 areas have their respective unit billets placed into the area without incurring any penalty, and an additional 19 areas are filled between 80 and 100 percent of t_a . These areas (representing just over half of the model areas currently utilized by MARFORRES) are not under particular demographic stress according to our assumptions.

80% (no penalty)		100%		124%		148%	176%	200%	Over 200%
a2	a51	a1	a53	a4	a32	a11	a27	a3	a16
a6	a56	a5	a55	a9	a44	a14	a29	a46	a18
a7	a61	a15	a57	a12	a50	a26	a48		a19
a10	a62	a17	a58	a13	a59	a45	a67		a24
a22	a66	a20	a63	a21	a60	a49	a70		a31
a30	a69	a34	a72	a23	a64	a52			a80
a36	a75	a35	a74	a28		a65			
a38	a78	a37	a79			a71			
a39	a81	a41	a84			a73			
a40	a82	a43				a76			
a42	a83								
a47									

Table 5. Percentage of t_a for unit billets placed in areas (2011 data). 23 areas have fewer than 80 percent of t_a billets and incur no penalty. All other areas have some penalty. The six areas over 200 percent of t_a comprise the largest penalty.

Table 6 shows the MCRO_out output file for the six most highly stressed areas. The differences in the “assigned” and “target” column in Table 6 illustrate the major problem for those areas. Each of them has significantly more billets than they should, based on an r_a of 400. The ratio of recruitable population to the number of MARFORRES billets in all of these areas is under 200. Each of these areas is, in effect, oversaturated with MARFORRES billets in comparison to the default recruitable population living there.

area	assigned	target	population	ratio
a16	625	168	67,265	107.6
a18	283	134	53,586	189.3
a19	220	80	32,160	146.2
a24	747	326	130,554	174.8
a31	111	50	19,854	178.9
a80	73	20	8,137	111.5

Table 6. MCRO_out data for the six most demographically stressed areas (2011 population data). For example, in area a16 MCRO places units totaling 625 billets, compared to a target number (t_{a16}) of 168. Parameter t_{a16} is calculated as $67,265 / r_{a16}$, where $r_{a16} = 400$ recruitable people per billet. The actual recruitable-people-per-billet ratio for the area is $67,265 / 625 = 107.6$.

B. MCRO BASE CASE 2036

This scenario is the base case for all of the unit movements under consideration in subsequent sections. It has the following attributes:

- All units are held to their current location.
- There are no units currently in a8 (Glenville/Albany, NY), a25 (Jackson, MS), a33 (Tallahassee, FL), a54 (Lafayette, LA), a68 (Saginaw, MI), or a77 (Reno, NV).
- It uses predicted net population data for 2036, based on BAH growth predictions and the 2011 QCP data.
- The value of r_a is set to default value of 400 for all areas.

The objective value of the model for this scenario (57,773) is significantly smaller than for the Base Case 2011 because the population of the U.S. is projected to increase in most areas through 2036, while the number of MARFORRES billets is assumed to remain constant. Table 7 shows the same information as Table 5, based on the 2036 population data.

80% (no penalty)			100%	124%	148%	176%	200%	Over 200%
a1	a35	a59	a9	a11	a3	a24	a19	a16
a2	a36	a60	a26	a12	a18	a31	a64	a57
a4	a37	a61	a27	a14	a29	a46		a80
a5	a38	a62	a32	a45	a48	a67		
a6	a39	a63	a34	a52	a70			
a7	a40	a65	a50		a76			
a10	a41	a66	a56					
a13	a42	a69	a71					
a15	a43	a72	a73					
a17	a44	a74	a79					
a20	a47	a75	a83					
a21	a49	a78						
a22	a51	a81						
a23	a53	a82						
a28	a55	a84						
a30	a58							

Table 7. Percentage of t_a for unit billets placed in areas (2036 data). 47 areas have fewer than 80 percent of t_a billets and incur no penalty. All other areas have some penalty. The three areas over 200 percent of t_a comprise the largest penalty.

The expected population growth over 25 years reduces the overall penalty incurred by MCRO to a significant degree. By 2036, 47 of 78 areas are filled with all assigned billets while incurring no penalty, and an additional 11 are filled within 100 percent of t_a . Of the six areas that were most demographically stressed in Base Case 2011, only a16 and a80 remain so by Base Case 2036. The other areas have population growth sufficient to alleviate some of the demographic stress they are experiencing with the number of billets currently located within them. The sole addition to the list of highest-stressed areas, a57, is Wahpeton, ND, because the BAH data predicts a significant downward trend in the population surrounding Wahpeton by 2036.

C. MCRO FULL CASE 2036

The base case shows how MCRO can illustrate demographic stress. We now use MCRO to prescribe unit moves to relieve that stress, and where MCRO would choose to

move these units, by feeding MCRO a Future_Unit_Areas data file that consists entirely of ones (except as noted below). This allows MCRO fully flexible choices to move any unit to any other area.

This scenario has the following attributes:

- All units are allowed to move to other locations.
- No units are allowed to move to a8 (Glenville/Albany, NY), a25 (Jackson, MS), a33 (Tallahassee, FL), a54 (Lafayette, LA), a68 (Saginaw, MI), or a77 (Reno, NV). Because there are currently no units in these locations, they would naturally attract the moving units, so they are excluded from consideration here.
- Predicted net population numbers for 2036, based on BAH growth predictions and 2011 QCP data are used.
- The value of r_a is set to default value of 400.

Table 8 shows the results of solving MCRO 10 times, in order to obtain results for allowing between one and 10 unit moves. These data have the Base Case 2036 scenario as a reference (objective function value 57,773). The number of unit moves allowed in the run is shown in columns across the top of the table. The particular unit, or group of units, which MCRO selects for movement and the areas from which they are moving, is shown in the two leftmost columns. The area that MCRO selects to move the unit to is shown in the columns corresponding to the number of unit moves allowed. The group of areas where MCRO selects to move the units, as well as the number of time MCRO chooses to move a unit to that area across all 10 model runs, is shown in the two rightmost columns. Finally, we show the objective function values at each number of moves, any areas that may have been vacated (i.e., all MARFORRES units removed from the area considered), the number of areas above 150 percent of t_a after the unit movements are complete, and the number of areas under 80 percent of t_a (which are incurring no penalty).

		Number of Allowed Unit Moves										Area	# of Moves To Area
From	Unit	1	2	3	4	5	6	7	8	9	10		
a46	M01136										a36	a22	9
a64	M29470									a62	a58	a51	7
a76	M21441								a20	a20	a43	a30	6
a24	M71707							a20	a1	a30	a20	a41	6
a67	M22324						a2	a2	a58	a2	a2	a43	6
a80	M21715					a35	a51	a1	a51	a51	a35	a20	5
a76	M14031				a51	a41	a41	a41	a22	a22	a22	a2	4
a57	M21723			a58	a43	a51	a30	a1	a36	a43	a51	a1	3
a46	M14301		a22	a22	a41	a22	a22	a22	a41	a51	a41	a58	3
a16	M21834	a22	a43	a43	a30	a43	a20	a30	a30	a62	a30	a35	2
												a36	2
												a62	2
Obj Function		46,636	41,309	37,061	33,117	29,563	26,831	24,188	21,822	19,508	17,698		
Areas over 150%		a16, a19, a24, a31, a46, a57, a64, a67, a80	a16, a19, a24, a31, a57, a64, a67, a80	a16, a19, a24, a31, a64, a67, a80	a16, a19, a24, a31, a64, a67, a80	a16, a19, a24, a31, a64, a67	a16, a19, a24, a31, a64	a16, a19, a31, a64	a16, a19, a31, a64	a16, a19, a31	a16, a19, a31		
Areas vacated		None	None	a57	a57	a57, a80	a57, a80	a57, a80	a57, a80	a57, a80	a57, a80		
# Areas under 80%		47	47	48	48	49	49	49	49	49	49		

Table 8. Results obtained by allowing MCRO to move units to seek the highest possible reduction in penalty. This table shows that units MCRO selects for movement based on the demographic strain they are under in their current area, and the areas in which MCRO places them.

For example, when restricted to a single unit move MCRO prescribes moving M21834, Alpha Co 4th AAV Battalion, from its current location in a16 to a22. By making this unit move, the model reduces the overall penalty incurred from 57,773 to 46,636. This large reduction in penalty is possible because of the demographics of the two areas, and because of the units that are already in these locations. M21834 is in Norfolk, VA, one of the subareas in area a16. This area is currently occupied by eight MARFORRES units (M01235, M01309, M01335, M01774, M03020, M14809, M21834, and M21837), which collectively sum to 625 ASR billets. Based on the predicted 2036 recruitable population for a16 of 108,308, and $r_{a16} = 400$, t_{a16} is 271 billets. In other words, a16 has nearly triple the number of billets that represent 80 percent of t_{a16} (216 billets). In contrast, area a22 (which includes Memphis, TN as its only major city) is currently occupied by only two MARFORRES units (M22316 and M22326), which together include only 116 ASR billets. By 2036, a22 is predicted to have 245,058 recruitable people, so t_{a22} in 2036 is 613 billets. The unit MCRO moves (M21834) is the largest unit in a16 at 199 ASR billets, and therefore moving it results in the largest penalty decrease possible for a16. By choosing to move it to a22, which can absorb a 199-billet unit and still remain well-under the 80 percent threshold (a22 could receive up to 394 additional billets before incurring penalties), MCRO incurs no additional penalty. It should be noted

that even after moving M21834, a16 is still a relatively highly stressed area in demographic terms (it is still among the areas over 150 percent of t_a).

The rest of the unit moves tabulated in Table 8 represent similar situations. In all cases, MCRO finds an area having high demographic stress, removes a large unit from that location and sends it to another area in which it incurs little or no penalty. There are many ways to achieve this result at each step. In fact, from Table 8 we observe that MCRO may prescribe a different relocation for the same unit when the allowed number of moves changes. For instance, M21834 alone is placed in five different areas depending on the total allowed moves. Another reason for this behavior is that there are many areas that can absorb the units being moved without incurring penalty. MCRO is indifferent between those choices, and thus there may exist multiple optimal solutions for each of the MCRO instances listed in Table 8.

Areas a57 and a80 (Wahpeton, ND and Billings, MT) merit special consideration in this discussion. Both areas, according to BAH's population predictions, will suffer a large drop in recruitable populations over the next 22 years. Though each area only has one MARFORRES unit, and both are fairly small (60 and 73 ASR billets, respectively), their predicted demographics are so poor that both are incurring a significant amount of penalty in the highest increment. Because the units are so small, and because the default value of r_a may be especially incorrect for these particular areas, their presence on this table should not necessarily be considered an indication that they are woefully misplaced. It is, however, indicative that these areas face a significant demographic challenge when compared to other areas.

Figure 5 illustrates how the value of the penalty function decreases as the number of unit movements MCRO allows increases. It reaches zero after 56 unit movements. This plot illustrates that there is a point of diminishing returns for MCRO with regards to unit movements. Roughly two-thirds of the total demographic penalty is removed from the solution within the first 10 unit movements. Once past that point, the marginal gains by additional moves are less significant.

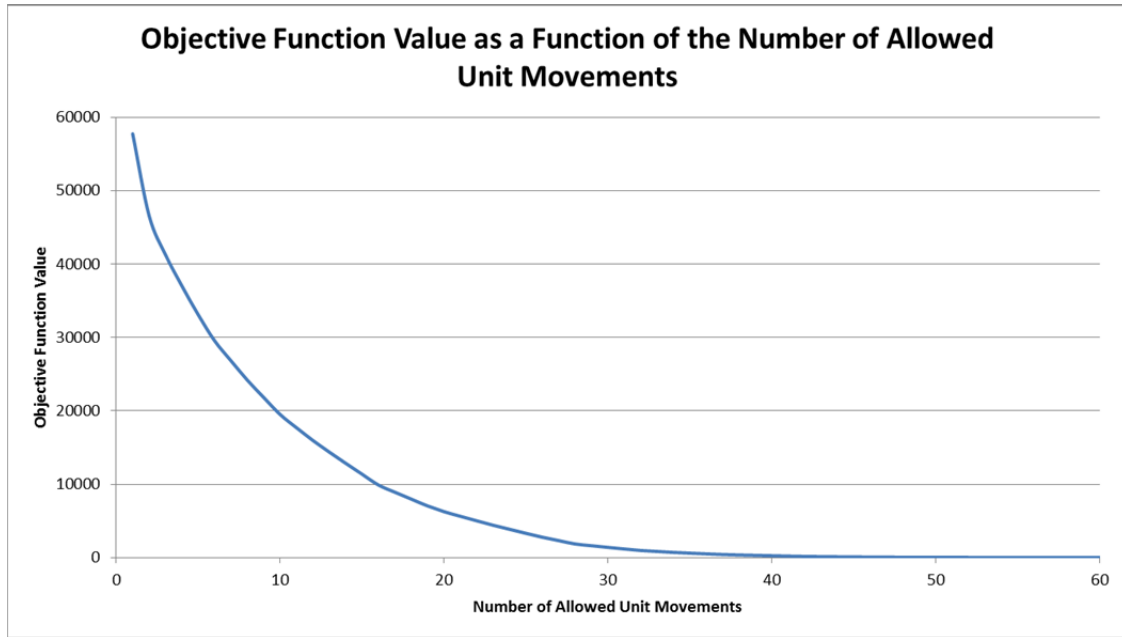


Figure 5. The value of the objective function decreases as the number of allowed unit movements increases. It reaches zero after 56 unit movements.

D. POTENTIAL UNIT MOVEMENT ANALYSIS

As this research neared completion, MARFORRES provided a set of possible unit movements they are currently considering for analysis. The following subsections describe the analysis of these scenarios using MCRO. The results of these analyses are comparable to the Base Case 2036 scenario unless otherwise noted (57,773). The recommendation to move or not move a given unit depends on how the demographic penalty of the alternative compares to the base case.

1. M14163 Scenario

MARFORRES is considering the movement of A Company, 1st Battalion 24th Marines (M14163) from its current location in Grand Rapids, MI to either Lansing, MI or Battle Creek, MI. All three of these are subareas of area a67 in MCRO within the established area-subarea architecture. As initially envisioned, MCRO was not intended to consider unit movements on such a small scale. However, such an analysis can be performed using MCRO by modifying the model inputs to treat these subareas as areas.

Because this is a completely new scenario, we must first establish a new base case. After reconfiguring the model inputs to consider only the a67 subareas, the base case for this scenario has an objective value of 11,721.

The possible receiving locations for this scenario are similar in terms of recruitable population, but significantly different in terms of the amount of billets already at the site. Lansing's recruitable population is about 60,700, while Battle Creek's is 52,100. However, Lansing currently has only 183 ASR billets, while Battle Creek has 309. Given Lansing's slightly larger population and comparative dearth of billets, it is obvious that Lansing is a better choice in demographic terms, and MCRO confirms this. The objective value rises to 16,133, because this unit movement represents adding some demographic stress to Lansing. If the user allows MCRO to consider leaving the unit in place in Grand Rapids, MCRO chooses this option with the same objective value as the base case.

However, in considering a unit movement within an area, it is important to remember that these sites are all relatively close to each other, and as such share a significant amount of recruitable population. Therefore, since the distance between Grand Rapids and Lansing is only 57 miles, it is likely that many potential recruits in the Grand Rapids area will also be potential recruits for the unit if it is in Lansing.

2. M14127 Scenario

The second scenario considers moving Weapons Company, 2nd Battalion, 23rd Marines (M14127) from Port Hueneme, CA to either Seal Beach, CA or to Phoenix, AZ. Similar to the M14163 scenario, Port Hueneme and Seal Beach are also in the same area (a76). However, Phoenix is in a41, so these two movement scenarios cannot be directly compared. To perform this analysis, we first establish if it is better to move M14127 to Seal Beach or to leave it in Port Hueneme, that is, within subareas in a76. Then, we run MCRO allowing the unit to be placed in either a41 or a76. The base case objective function value for this scenario for all a76 subareas is 122,281. The a76 base case value is

extremely high because of the large number of units in a76 (27 total), and because only 10 of a76's 14 subareas are occupied, meaning that several of the subareas have very high penalty when a76 is considered as an area.

In demographic terms, the decision of whether to move M14127 from Port Hueneme to Seal Beach is similar to the option between Lansing and Battle Creek. By recruitable population, Seal Beach has a sizable advantage over Port Hueneme (approximately 81,500 and 65,000, respectively). However, Seal Beach already has significantly more billets than Port Hueneme. M14127 has only 126 ASR billets, and is the only MARFORRES unit at Port Hueneme. Seal Beach has three units comprised of 490 ASR billets, and as such is incurring penalty in the maximum increment within a76. Therefore, the movement of M14127 from Port Hueneme to Seal Beach is not recommended on any demographic grounds. If we force MCRO to make this unit movement, the objective value rises from 122,281 to 134,881.

MCRO does recommend moving M14127 from a76 to a41. The BAH data predicts that the population of the Phoenix and Tucson, AZ region will grow much faster than most of the rest of the U.S. over the next 20 years. Moving M14127 to Phoenix relieves some of the demographic stress on the southern CA region, while not causing any penalty in Phoenix (even with M14127 added to a41, the area is still under 80 percent of t_{a41}). By itself, this movement reduces the total demographic penalty across all areas from 57,773 in the base case to 56,072.

3. M14404, M14411, and M14412 Scenario

This scenario considers moving Company B, 4th Combat Engineer Battalion (CEB) (M14404), Detachment 2, H&S Company, 4th CEB (M14411), and Detachment 2, Engineer Support Company, 4th CEB (M14412), from their current location in Roanoke, VA, to either Lynchburg, VA, or Broken Arrow, OK. Roanoke and Lynchburg are part of area a18, while Broken Arrow is part of area a52, so this analysis follows the same steps as the analysis for the M14127 scenario.

When considering the movement of these units within area a18, the base case objective value is 1,199. Lynchburg has approximately 50 percent more recruitable

population than Roanoke (46,100 and 31,700, respectively). They also currently have a nearly identical number of billets (140 and 143, respectively). Thus, Lynchburg can add a portion of the billets currently assigned to Roanoke, but not all, as the transfer of all billets to Lynchburg would create more penalty. Forcing MCRO to move all units to Lynchburg causes a significant increase in the penalty to 7,251. If MCRO is allowed to place any of the six units in either Lynchburg or Roanoke, the optimal solution involves moving M14411 and M14412 to Lynchburg, which reduces the penalty to 996. However, as with the M14163 scenario, when one considers that the distance between the two cities is only 44 miles, and that the recruitable populations of the cities are therefore not exclusive, moving all of the units to Lynchburg may not be as demographically stressful as MCRO is indicating.

Giving MCRO the option to either move the three units to a52, or to leave them in place in a18, results in M14411 and M14412 being moved to a52, while M14404 remains in a18. Without considering unit movements, both a18 and a52 are under some amount of demographic stress; a18 is filled with billets to 145 percent of t_{a18} , while a52 is at 117 percent of t_{a52} . Moving those units reduces t_{a18} to 130 percent, while only increasing t_{a52} to 127 percent. This results in a very small reduction in the model's overall penalty, from 57,773 to 57,656. We conclude that such a small benefit is not likely worth the expense of the move. This analysis does not consider it necessary for M14404, M14411 and M14412 to be collocated units. If they must be, then MCRO recommends leaving all three units in a18.

4. M01774 Scenario

This scenario considers the re-designation of Marine Medium Helicopter Squadron 774 (HMM-774) to Medium Tiltrotor Squadron 774 (VMM-774) (M01774), and analyzes whether to move it from its current location in a16 to a14. Area a14 includes Marine Corps Air Station New River in NC. Because the unit is being re-designated as a VMM, this involves a slight reduction in the number of billets assigned to the unit (the HMM rates 102 ASR billets, while the VMM rates 94).

As seen in previous examples, a16 is among the most demographically stressed in MARFORRES, and MCRO recommends moving M01774 from a16 to a14. Area a14 is under comparatively slight demographic stress in the base case (it is filled to about 103 percent of t_{a14} in the base case). Moving M01774 to a14 increases this stress to 152 percent, but creates enough relief in a16 to take it out of the highest tier of penalties. By itself, this unit movement reduces the model penalty from the base case of 57,773 to 49,976.

VII. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

In this chapter, we make some observations about MCRO in its current form, and discuss potential avenues for improvement.

A. CONCLUSIONS

MCRO is an initial attempt at optimizing a problem that has existed for years. Demographic concerns are only one of the many factors that play a role in the optimal location of MARFORRES units, but they are arguably the most important ones. While facilities and costs are certainly important, MARFORRES units exist so that they can be called upon when needed, and units are much more useful if they are adequately staffed when called.

As currently configured, MCRO is capable of aiding MARFORRES make decisions about placement of units with respect to demographics. While MCRO stands on its own as a useful tool for MARFORRES in this form, it can be improved in several respects. Some of these involve refining MCRO's data inputs, and others are additions to the model. The following sections consider a few of the possibilities that we believe can make MCRO a much more useful tool.

B. CUSTOMIZATION OF TARGET RECRUITING RATIO BY AREA

MCRO is using a default target recruiting ratio (r_a) for all areas. This default value is the result of dividing the total number of recruitable people residing in all MCRO areas by the total number of MARFORRES billets in those areas. By the 2011 population, this is approximately 400 recruitable persons per MARFORRES billet, and closely agrees with the number MARFORRES personnel were using as an estimate during FSRG planning [3].

However, even a cursory look at M&RA's population data indicates that the value of r_a should almost certainly not be the same for all areas. Table 9 is an excerpt of that data, for the subareas included in area a16.

UIC	CITY_CD	MSC	ORG_NAME	MATCH	EXCESS	ONHAND	MATCH/OH	DISCREPANCIES	OPEN	ASR	PERSONNEL	MOS_FILL
M14809	OCEANA	FHG	DET 1 CI/ HUMINT CO B ISB FHG MARFORRES	0	6	16	0.00%	10	0	34	47.10%	0.00%
M01774	NORFOLK	MAW	HMM-774 MAG-49 4TH MAW	80	15	104	76.90%	9	20	102	102.00%	78.40%
M01309	OCEANA	MAW	HQTRS MACS-24 MACG-48 4TH MAW	118	53	173	68.20%	2	22	140	123.60%	84.30%
M01235	OCEANA	MAW	DET TAOC MACS-24 MACG-48 4TH MAW	48	10	60	80.00%	2	20	70	85.70%	68.60%
M21834	NORFOLK	DIV	AAV CO A 4TH AAV BN 4TH MARDIV	123	24	148	83.10%	1	74	199	74.40%	61.80%
M03020	NORFOLK	MAW	SITE SPT (NORFOLK VA) MAG-49 4TH MAW	1	0	2	50.00%	1	0	1	200.00%	100.00%
M01335	OCEANA	MAW	DET EW/C MACS-24 MACG-48 4TH MAW	29	11	40	72.50%	0	33	63	63.50%	46.00%
M21837	NORFOLK	DIV	DET 1 H&S CO 4TH AAV BN 4TH MARDIV	13	1	14	92.90%	0	2	16	87.50%	81.30%

Table 9. Sample M&RA data for reserve unit staffing in southeastern Virginia (model area a16). The “ON HAND” column shows the number of active Marines at the unit, and the “ASR” column shows the number of billets the unit rates, from [4].

The most pertinent numbers in Table 9 are those in the columns “ON HAND” and “ASR.” These represent the number of Marines (as of February 2014) who are active members of each unit, and the number of billets in each unit, respectively. If we use the default value of r_a , t_{a16} is 168 billets, for a local recruitable population of 67,265 in 2011. The on-hand number of Marines in a16 is 557, which falls short of the total of 625 billets in the area, but exceeds MCRO’s calculated t_{a16} based on its recruitable population significantly. It appears that predicting an ability to recruit only one out of 400 eligible people in a16 is somewhat pessimistic, because more than three times t_{a16} are currently active members of MARFORRES units in that area.

A counterpoint to this example is shown in Table 10. It shows two units, both in upstate New York, each of which is the only unit in its respective model area (M14214 is in model area a6, and M14040 is in a7). The number of billets belonging to each unit is less than the model’s threshold for penalties in those areas, even with the lower 2011 population. However, according to these data, both units are undermanned. It should also be noted that both of these are ground combat units, which according to anecdotal evidence are usually among the easier types of units for MARFORRES to fill [3]. In a6 and a7, the reverse conclusion must be drawn: successfully recruiting one in 400 people in these areas appears to be overly optimistic.

UIC	CITY_CD	MSC	ORG_NAME	MATCH	EXCESS	ONHAND	MATCH/OH	DISCREPANCIES	OPEN	ASR	PERSONNEL	MOS_FILL
M14214	BUFFALO	DIV	RFL CO C 1/25 4TH MARDIV	142	18	164	86.60%	4	40	183	89.60%	77.60%
M14040	SYRACUSE	DIV	LAR CO E 4TH LAR BN 4TH MARDIV	109	15	133	82.00%	9	29	144	92.40%	75.70%

Table 10. Sample M&RA data for reserve unit staffing in upstate New York (model areas a6 and a7), from [4].

The two examples above indicate that while the average r_a across the country may be 400 recruitable persons per billet in 2011 population numbers, the optimal value of r_a may vary substantially between different areas. It is possible that an analysis of the historical staffing rates for units within the model's areas, the metrics of reserve unit health discussed in Chapter I (both of these with respect to unit type), and possibly other factors might lead to determining a better estimate of r_a for each individual area. These more accurate numbers would improve MCRO's ability to place units appropriately. Some work in this area has already been done, though it is somewhat dated [14].

One might base a starting point for an estimate of r_a across model areas on the data above. For instance, if a16 has a recruitable population of 67,265, and 557 personnel are actively participating in reserve units in a16, perhaps an initial r_a for a16 should be $67,265 / 557 \approx 121$ recruitable personnel per billet. However, it may be desirable to include a small safety factor in such an estimate. It is also probable that the various values for r_a will change over time with changing population numbers.

C. POPULATION DATA

While both sources of population data used in this thesis and the method by which they are combined are acceptable, it is likely that more accurate estimates for recruitable population by area may be acquired. U.S. Census Bureau data [11] was frequently consulted during this analysis, in most cases to confirm or refute apparent discrepancies encountered between the two data sets. In the course of performing these various tasks, it becomes apparent that the ideal data set for this analysis would be a modified version of BAH's population counting method.

A distinguishing feature of the MCRC data set is that it does not share populations across the state and county boundaries it uses. However, this also means that it discounts a significant amount of population that is technically available to other areas. For

instance, in the northeast part of the U.S., some of the model areas are comparatively small in geographic terms and share borders. The distance between Washington, DC and Boston is just less than 400 miles, but the corridor along the seaboard between the two cities includes six of MCRO's areas and over two million of the available recruitable population of the entire country. It is clear that substantial portions of the populations of each of those areas must be available to their neighbors, particularly when one considers that the HTCs in these areas are often not centrally located in their respective area.

Conversely, the 100-mile radius the BAH data covers has more merit in some parts of the country than others. As an example, according to the MCRC population data, the recruitable population of area a1 including Philadelphia is less than half that of the population in area a9, which includes New York City. In the BAH data, because these cities are within 100 miles of each other, their populations are very similar. However, it is very unlikely that a resident of one city would seriously consider joining a reserve unit in the other city, due to the difficulties of traveling between them. This means that, while the populations within 100 miles of Philadelphia and New York City may be similar, the numbers that each can effectively recruit should be significantly different.

The ideal population data set for use with MCRO would be built with these realities in mind. A possible algorithm might involve starting with a given HTC site, and building distance tiers around it out to 100 miles. Each tier would include the recruitable population within it, multiplied by a probability that a recruit in that tier would choose to join a unit at that HTC, and de-conflicted with collocated and adjacent reserve units to account for population sharing. Such a data set could be built using the same method BAH uses in determining population, with the additional steps of counting the population around the HTCs in several circular areas instead of just one, and accounting for shared populations between HTCs where they exist. Once this data set is built on current populations at these sites, the same ARIMA model BAH uses to project population growth could be applied, yielding a recruitable population prediction over time in a form that would be much more useful for this type of analysis.

This data set would enable eliminating the current area-subarea architecture MCRO uses, and allow treating the subareas as areas. This would yield a much more detailed analysis than MCRO is currently performing.

D. ADDING FACILITY AND COST DATA

There are other factors besides demographics that affect the ability of MARFORRES to place units in various locations, some of which have been mentioned. The two most important are facility and cost considerations.

MARFORRES has a significant amount of data in regards to the facilities that it utilizes as HTCs, and on other facilities that it has used in the past or could use in the future. In general terms, facilities are rated based on the Commanding Officer's Readiness Reporting System (CORRS). CORRS is a simple system that rates facilities "...on their condition and quantity, and commanders rate the ability of their plant facilities to achieve mission requirements" [15]. In other words, facilities are rated both by their state of repair and their suitability for the unit that is placed there. A brand new office building, for example, may achieve the highest possible CORRS assessment with respect to the condition of the facility, but it would receive the lowest possible quantity rating if a truck maintenance company were assigned to that facility, because the facility is not adequate for that unit's mission.

Many facilities currently occupied by MARFORRES units do not rate particularly well on the CORRS scale for the units that utilize them. One of the reasons for this is that MARFORRES does not actually own many of these facilities: they are often rented as space available on a military post belonging to one of the other services. Because these facilities are generally not purpose-built for the type of MARFORRES unit utilizing them, they are often not well-suited to the mission.

MCRO is currently capable of taking facilities into account in a limited fashion; for instance, if a facility capable of acting as an HTC for a unit does not exist in a given area, one simply does not allow MCRO to consider moving the unit to that area. However, the model could benefit from an ability to handle MARFORRES' various

facility problems explicitly, and we believe that adding this capability to the mathematical model is possible, albeit it may complicate its solvability.

Cost considerations with respect to unit movements cover a wide range of factors. These include, but are not limited to:

- Cost of new military construction to accommodate units
- Costs of moving a unit
- Costs of accepting reduction in mission capability of a moved unit for a certain amount of time following movement
- Operation and maintenance (O&M) cost comparisons between prospective unit locations over time
- Costs of re-purposing facilities

The most difficult part of estimating these costs will likely be in comparing the long-term O&M costs between different areas, unless some framework for conducting such an analysis already exists. The BRAC studies cited in the references mention a tool known as Cost of Base Realignment Actions (COBRA) as a “...mandatory tool for evaluating BRAC costs and savings” [9]. COBRA is “...a quantitative model...to estimate potential costs and savings of various BRAC options and compare them” [16]. According to [16], COBRA has been applied to reserve concerns in the past.

As with facilities, MCRO is currently capable of accounting for cost factors in a limited fashion. However, doing so depends on the user’s knowledge of the differences in various costs between areas. Incorporating the cost-estimating method used in COBRA, or a similar paradigm, would significantly enhance MCRO’s capabilities.

APPENDIX. MCRO AREAS AND SUBAREAS

This section lists MCRO's areas and subareas (Table 11). The MCRC population data lists some, but not all, of the subareas BAH uses in their work. Where appropriate, any BAH subarea not explicitly referenced in the MCRC data has been included within the MCRC area it best fits geographically (these additional BAH subareas are shown in italics in Table 11). For example, the MCRC data for area a4 lists Cincinnati, Columbus and Dayton, OH, as its regions. The BAH data includes all of these, as well as the BAH subarea of Wright-Patterson Air Force Base, which is close to Dayton.

Model Area	Included Subareas
a1	Bristol, PA Folsom, PA Naval Air Station Willow Grove, PA Philadelphia, PA Wilmington, DE <i>Joint Base McGuire-Dix-Lakehurst, NJ</i> <i>West Trenton, NJ</i>
a2	Harrisburg, PA Reading, PA <i>Lehigh Valley, PA</i> <i>Wyoming, PA</i>
a3	Ebensburg, PA Johnstown, PA North Versailles/Pittsburgh, PA <i>Moundsville, WV</i>
a4	Cincinnati, OH Columbus, OH Dayton, OH <i>Wright-Patterson Air Force Base, OH</i>
a5	Akron, OH Brook Park/Cleveland, OH Erie, PA <i>Youngstown, OH</i>
a6	Buffalo, NY Rochester, NY
a7	Syracuse, NY
a8	Albany, NY <i>Glenville, NY</i>
a9	Brooklyn/New York City, NY

Model Area	Included Subareas
	Stewart Air National Guard Base/Newburgh, NY Picatinny Arsenal, NJ Red Bank, NJ Amityville, NY Farmingdale, NY Garden City, NY
a10	New Haven, CT Plainville, CT
a11	Ayer/Boston, MA Chicopee, MA Fort Devens, MA Londonderry, NH <i>Westover Army Reserve Base, MA</i> <i>Providence, RI</i>
a12	Topsham, ME <i>Naval Air Station Brunswick, ME</i>
a13	Fort Knox, KY Lexington, KY
a14	Camp LeJeune, NC <i>Stone Bay, NC</i>
a15	Greensboro, NC Raleigh, NC
a16	Dam Neck, VA Joint Expeditionary Base Little Creek-Fort Story/Virginia Beach, VA Naval Air Station Norfolk, VA Newport News, VA
a17	Richmond, VA
a18	Lynchburg, VA Roanoke, VA
a19	Camp Upshur/Quantico, VA
a20	Baltimore, MD Fort Detrick/Frederick, MD Joint Base Andrews, MD Joint Base Anacostia-Bolling, DC
a21	Chattanooga, TN Knoxville, TN Smyrna/Nashville, TN
a22	Memphis, TN
a23	Johnson City, TN
a24	Baton Rouge, LA Marine Corps Support Facility New Orleans, LA Naval Air Station/Joint Reserve Base New Orleans, LA Naval Construction Battalion Center Gulfport, MS

Model Area	Included Subareas
a25	Jackson, MS
a26	Bessemer, AL Montgomery, AL
a27	Mobile, AL Naval Air Station Pensacola, FL
a28	Huntsville, AL
a29	Hunter Army Airfield/Savannah, GA Joint Base Charleston, SC North Charleston, SC
a30	Augusta, GA Marietta/Smyrna, GA Naval Air Station Atlanta, GA Robins Air Force Base/Warner Robins, GA <i>Dobbins Army Reserve Base, GA</i> <i>Forest Park, GA</i> <i>Rome, GA</i>
a31	Marine Corps Logistics Base Albany, GA
a32	Fort Jackson/Columbia, SC
a33	Tallahassee, FL
a34	Jacksonville, FL
a35	Orlando, FL Tampa, FL
a36	Hialeah/Miami, FL West Palm Beach, FL
a37	Greenville, SC
a38	Charlotte, NC
a39	Fort Buchanan, PR
a40	Marine Corps Air Station Yuma, AZ
a41	Phoenix, AZ Davis-Monthan Air Force Base/Tucson, AZ <i>Luke Air Force Base, AZ</i>
a42	Albuquerque, NM <i>Kirtland Air Force Base, NM</i>
a43	Buckley Air National Guard Base/Denver, CO <i>F.E. Warren Air Force Base, WY</i>
a44	El Paso, TX
a45	Amarillo, TX Lubbock, TX
a46	Dyess Air Force Base/Abilene, TX Grand Prairie/Dallas, TX Naval Air Station/Joint Reserve Base Fort Worth, TX Waco, TX
a47	Austin, TX Joint Base San Antonio, TX

Model Area	Included Subareas
a48	Bossier City, LA Texarkana, TX
a49	North Little Rock, AR
a50	Harlingen, TX Naval Air Station Corpus Christi, TX
a51	Ellington Field/Houston, TX Galveston, TX
a52	Broken Arrow, OK Oklahoma City, OK <i>Tulsa, OK</i>
a53	Wichita, KS
a54	Lafayette, LA
a55	Kansas City, MO Topeka, KS <i>Belton, MO</i>
a56	Omaha, NE
a57	Wahpeton, ND
a58	Minneapolis, MN <i>Fort Snelling, MN</i>
a59	Green Bay, WI
a60	Madison, WI Milwaukee, WI
a61	Springfield, MO
a62	Bridgeton/St. Louis, MO
a63	Chicago, IL <i>Fort Sheridan, IL</i> <i>Joliet, IL</i> <i>Lake County, IL</i> <i>Naval Station Great Lakes, IL</i> <i>Waukegan, IL</i>
a64	Peoria, IL Rock Island Arsenal, IL
a65	Grissom Army Reserve Base/Peru, IN Indianapolis, IN Terre Haute, IN
a66	Perrysburg, OH Selfridge Army National Guard Base/Detroit, MI
a67	Battle Creek, MI Grand Rapids, MI Lansing, MI South Bend, IN
a68	Saginaw, MI
a69	Joint Base Lewis-McChord, WA
a70	Yakima, WA

Model Area	Included Subareas
a71	Spokane, WA
a72	Eugene, OR Portland, OR <i>Lane County, OR</i>
a73	Gowen Field/Boise, ID
a74	Sacramento, CA San Bruno/San Francisco, CA <i>Alameda, CA</i> <i>Camp Parks, CA</i> <i>Concord, CA</i> <i>San Joaquin Depot/Lathrop, CA</i> <i>San Jose, CA</i>
a75	Bakersfield, CA Fresno, CA <i>Naval Air Station Lemoore, CA</i>
a76	Bell/Los Angeles, CA Camp Delmar/Camp Pendleton, CA Naval Base Ventura County/Port Hueneme, CA San Diego, CA Twentynine Palms, CA <i>Edwards Air Force Base, CA</i> <i>Long Beach, CA</i> <i>Los Alamitos, CA</i> <i>Los Flores, CA</i> <i>Marine Corps Air Station Miramar, CA</i> <i>Moreno Valley, CA</i> <i>Naval Weapons Station Seal Beach, CA</i> <i>Pasadena, CA</i> <i>Pico Rivera, CA</i>
a77	Reno, NV
a78	Nellis Air Force Base/Las Vegas, NV
a79	Camp Williams Army Reserve Base/Riverton, UT Salt Lake City, UT
a80	Billings, MT
a81	Joint Base Elmendorf-Richardson/Anchorage, AK
a82	Marine Corps Air Station Kaneohe Bay, HI
a83	Des Moines, IA
a84	Charleston, WV

Table 11. List of model areas and included subareas.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

- [1] Marine Forces Reserve. (2014). “2014 Almanac Special Issue.” Continental Marines. [Online]. Available:
<http://www.marforres.marines.mil/Portals/116/Docs/ConMar/Almanac6.pdf>
- [2] M. Dolfini-Reed, L. Malone, A. Gyekye, T. Kimble and L. Lee, “Demographic Dynamics of the Reserve Force Laydown,” Center for Naval Analyses, Alexandria, VA, Rep. CRM D0025181.A2/Final, 2011.
- [3] G. Ormerod, C. Ullman and S. Wonderlich, private communication, Dec. 2013.
- [4] A. Licari, private communication, Mar. 2014.
- [5] Microsoft Excel, Redmond, WA, Microsoft, 2010.
- [6] Booz Allen Hamilton, “BAH_MFRSURVIAC_LRP-Modeling Workbook,” unpublished.
- [7] Booz Allen Hamilton, “Manpower Analysis Portfolio of Tools,” unpublished.
- [8] R. F. Dell, “Optimizing Army Base Realignment and Closure,” *Interfaces*, vol. 28, no. 6, pp. 1–18, Nov. 1998.
- [9] R. F. Dell, P. L. Ewing and W. J. Tarantino, “Optimally Stationing Army Forces,” *Interfaces*, vol. 38, no. 6, pp. 421–435, Nov. 2008.
- [10] J. Mitchell, private communication, Apr. 2014.
- [11] U.S. Census Bureau. (2014). “State and County Quickfacts.” [Online]. Available:
quickfacts.census.gov.
- [12] Generalized Algebraic Modeling System (GAMS), Washington, DC, GAMS Development Corporation, 2013.
- [13] GAMS/Cplex 12, Washington, DC, GAMS Development Corporation, 2013.
- [14] A. J. Cacciatore, “Factors Affecting Chronically Short Military Occupational Skill (MOS) Specialties in USMC Reserve Units,” M.S. thesis, Operations Research Department, Naval Postgraduate School, Monterey, CA, 1999.
- [15] U.S. General Accounting Office, “Military Infrastructure: Real Property Management Needs Improvement,” U.S. General Accounting Office, Washington, DC, Rep. GAO/NSIAD-99-100, 1999.

- [16] U.S. Government Accountability Office, “Military Bases: Opportunities Exist to Improve Future Base Realignment and Closure Rounds,” U.S. Government Accountability Office, Washington, DC, Rep. GAO-13-149, 2013.
- [17] Google Earth, Mountain View, CA, Google, Inc., 2013.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
Ft. Belvoir, Virginia
2. Dudley Knox Library
Naval Postgraduate School
Monterey, California